# Proton Test Guideline Development - Lessons Learned

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DTRA RHM

# PURPOSE OF DOCUMENT

- To guide the engineer doing proton testing for Single Event Effects (SEE), Total Ionizing Dose (TID) and Displacement Damage (DD) or Displacement Damage Dose (DDD)
- Attention to the issues raised in this document should enhance the efficiency of testing and assist in generating valid data
- This “lessons learned” document is based on many man-years of testing experience
- Reader referred to references for more complete explanation of the issues involved

# PURPOSE OF DOCUMENT

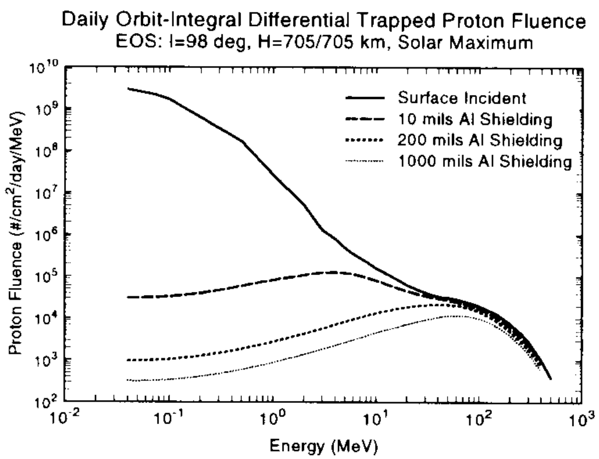
- **IT IS NOT A TEST METHOD...**

  but it does highlight some of the issues that would normally be included in a test method document, including specifications for proton energy, proton flux, number of devices, etc.

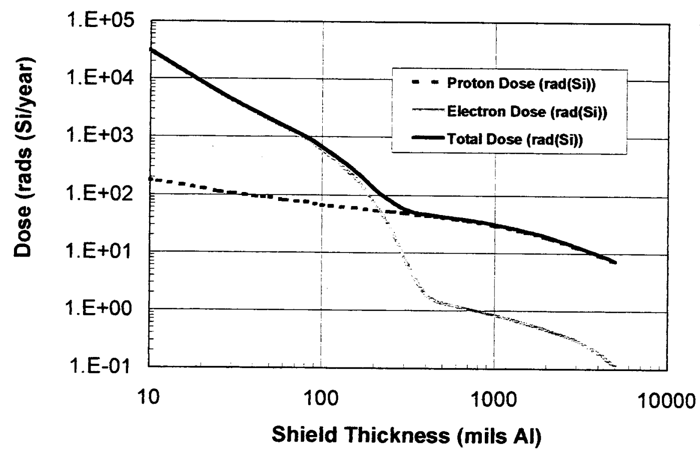
# OUTLINE OF DOCUMENT

- General Introduction
- Description of proton test facilities
- Dosimetry
- General issues for proton testing
- Specific issues for proton-induced SEE testing
- Specific issues for proton-induced TID testing
- Specific issues for proton-induced DDD testing
- Case studies - combined effects
- Conclusions and Summary
- References

- Brief description of radiation environment including the effects of shielding.




Proton fluence vs energy




Effect of shielding

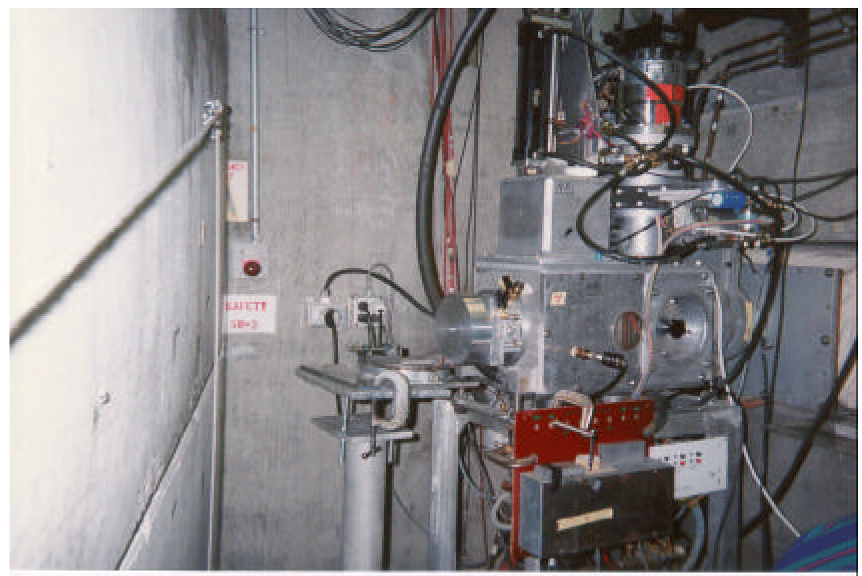
# GENERAL INTRODUCTION

- Why proton testing is done:
  - No SEE or DDD data exists for parts to be used in proton-rich environment
  - Heavy-ion SEE data suggests sensitivity to SEE by protons
  - The parts are COTS with large lot-to-lot variations in DDD
  - To measure SEE sensitivity of part that cannot be de-lidded
  - Neutron data exists suggesting marginal performance
  - The parts may exhibit both TID and DDD
  - The parts may be sensitive to SEE via direct ionization
  - The parts may be sensitive to proton induced latchup

# TEST FACILITIES

- Description
  - Internet home page
  - Point of contact
  - Type of accelerator
  - Energies available
  - Beam structure -size, temporal shape
  - Beam location
  - User interface
  - Support facilities
  - Length of cabling required
  - Dosimetry
  - Travel to site

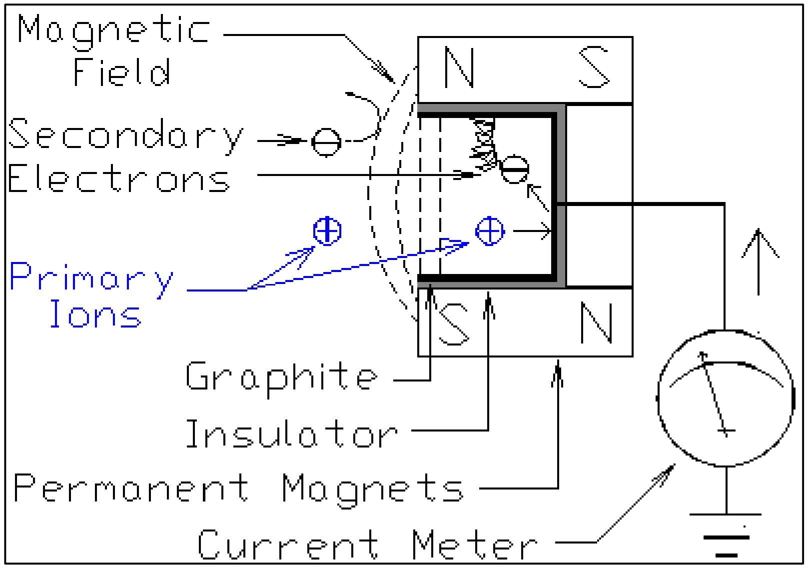
Crocker Nuclear Laboratory



# DOSIMETRY

- Standard methods of dosimetry
  - Secondary Electron Emission Monitor (SEEM)
  - Scintillators/photomultipliers
  - Faraday Cup
  - Radiochromic dye film

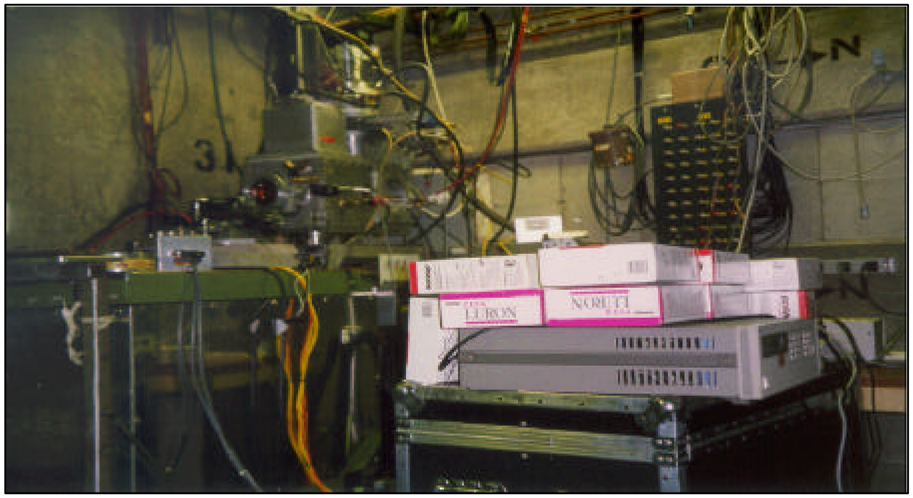
Faraday Cup



# GENERAL ISSUES FOR PROTON TESTING

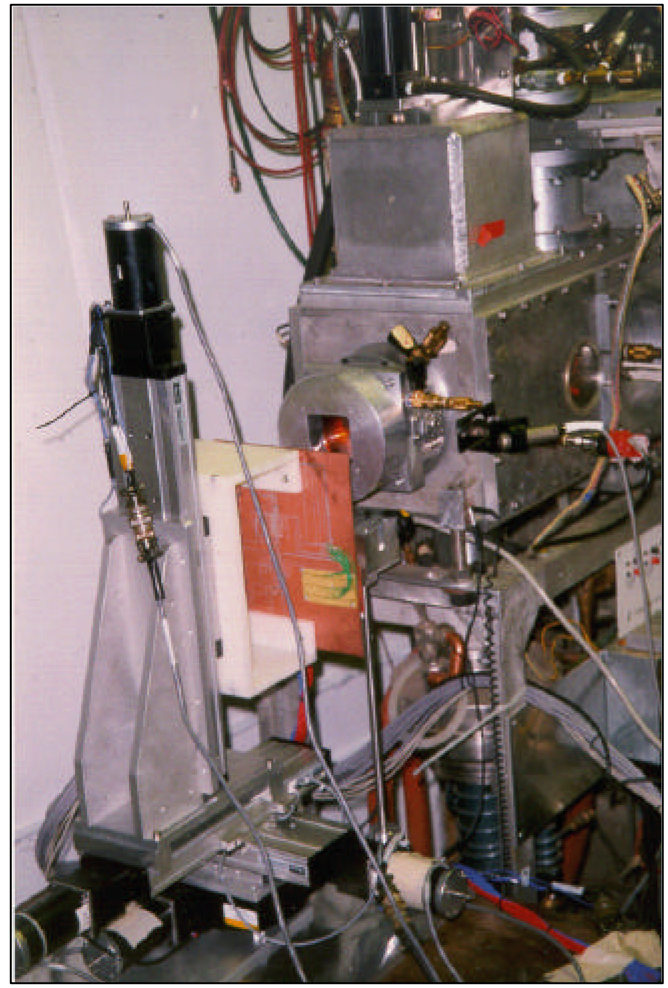
- Safety issues
- Implications of testing in air
- Device alignment and stage
- Protecting test equipment against radiation damage
- Remote control of the test equipment - cables, testing at speed
- Irradiating packaged parts - range of protons
- Use of apertures to control beam diameter - # of parts, radioactivity
- How to calculate proton ionizing energy loss with SRIM2000
- Use of degraders to reduce proton energy - save time, straggle, angular dispersion, use of SRIM2000

# SETUP



Protecting equipment against secondary neutrons with Borax

Remotely operated stage for testing more than one device without entering vault and at angles. Also collimation for restricting exposure.

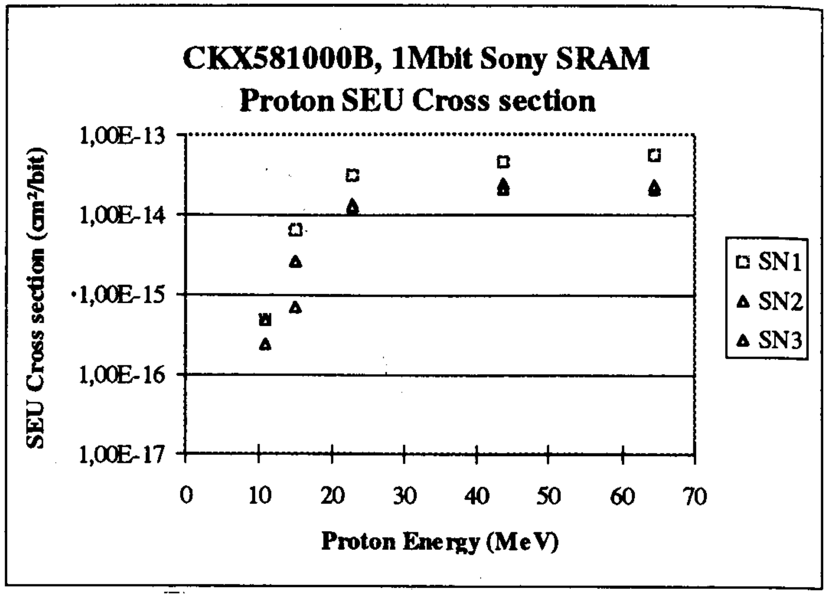


# PROTON-INDUCED SEE TESTING

- Description of mechanisms responsible for SEEs
- Specific issues:
  - Proton energy - package penetration, cross-section curve
  - Proton flux - efficiently capture SEEs, cost of beam time
  - Proton fluence - statistics
  - Effects of packaging
  - Protecting against latchup and cold restarting
  - Issues related to SEE testing of specific devices
    - Multiple-bits in SRAMs and DRAMs
    - Non-normal incidence in modern devices
    - and many more…
  - Data analysis
    - 1-parameter Bendel, 2-parameter Bendel, Weibull, PROFIT

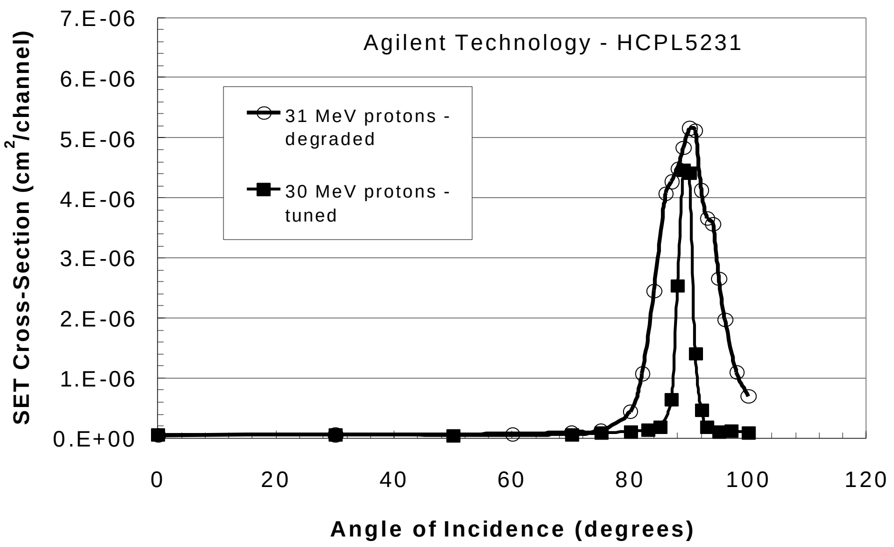
# PROTON-INDUCED SEE TESTING

- **Proton Energy**
  - **Number of different energy points - generating s vs E curve**
  - **Degrading or re-tuning beam**
  - **Error bars, determined by sqrt(# of errors)**



# PROTON-INDUCED SEE TESTING

- **SEE testing of detectors - direct vs indirect ionization.**
- **Dependence on angle of incidence**
- **Use of degraders vs tuned beam energies**

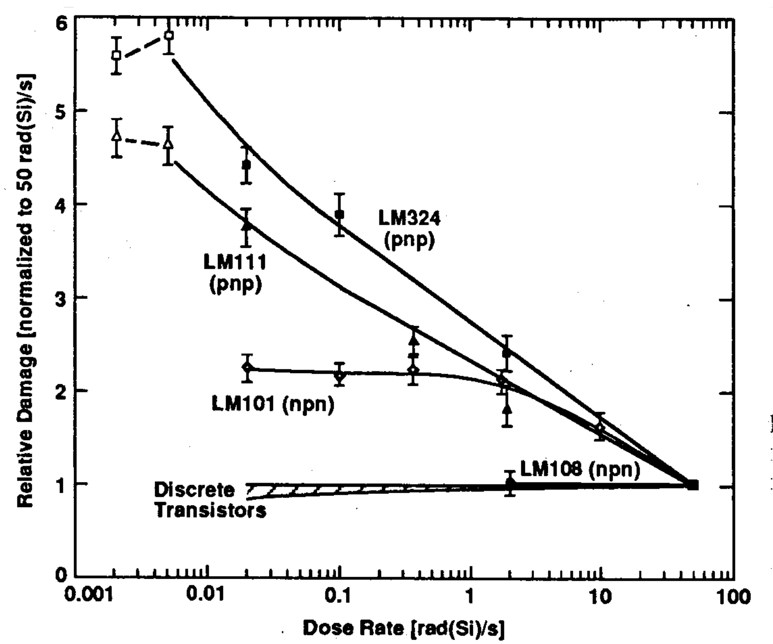


# PROTON-INDUCED TID TESTING

- Description of Mechanisms responsible for TID
- Specific Issues
  - Proton-testing for TID rarely cost effective and microdosimetry may differ for electron or gamma ray dominated environments
  - Testing according to Mil. Std. 883 Test Method 1019.5
  - Limitations of TID testing with protons - ELDRS
  - Proton energy
  - Proton flux
  - Proton fluence
  - Number of devices for hardness assurance

# PROTON-INDUCED TID TESTING

- Mil. Std. 883 Test Method 1019.5 specifies dose rate
  - Beam current -> proton flux -> dose rate
- Problems with ELDRS



# PROTON-INDUCED DD TESTING

- Description of mechanism responsible for DD
- Specific Issues
  - Proton energy
  - Proton fluence
  - Proton flux
  - Limitations of Non-Ionizing Energy Loss (NIEL) calculations
  - Electrical bias during testing
  - Delay be between exposure and testing
  - Role of background neutrons

# PROTON-INDUCED DD TESTING

- Correlations of proton energy dependent damage with calculated NIEL
  - To first order, correlations show that testing at a limited set of proton energies can enable orbital predictions
  - Evidence for deviations from linear correlation of damage with NIEL may affect agreement at either low or at high proton energies. Single energy predictions are risky
  - Choice of the proper damage factor, e.g., what is the correct damage factor for CCD cameras - either charge transfer efficiency or dark current. This can lead to factors greater than 2 difference in on-orbit predictions
  - Fidelity between damage and NIEL energy dependencies can show different trends depending on damage mechanisms, device physics, and material systems
  - Correlations are better in Si than in GaAs and InGaAs. Other materials still questionable

# CASE STUDIES

- Single Event Effects
  - Solid state recorder -> low SEU cross-section but TID sensitive
  - Fiber optic data links -> direct ionization, hardware dependent
  - High-speed technologies -> in-situ testing, board development
- Displacement Damage
  - Optocouplers -> TID+DD, drive current and output load dependent
  - CCDs -> passive incremental exposures
- Board Level Testing
  - Single board computers
  - Challenges of instrumentation and software development where DUT access is indirect

# SUMMARY AND CONCLUSIONS

- Generated a compilation of descriptions of test facilities, their major characteristics, logistic details and lessons learned through hundreds of tests so that designers, test engineers and managers can better appreciate the benefits and challenges inherent in discovering how a given device might respond in orbit

- Our document covers three important areas as well as discussions of combined effects with case studies and extensive references to archival literature and test reports

# SUMMARY AND CONCLUSIONS

- Emphasis is for NASA needs, but plans are to complete internal review draft ASAP and make available to the general community shortly thereafter

- We are interested in providing this as input into the Test Method Development, but our document complements those objectives more than it achieves them